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The Linac Control System After the 400 MeV Upgrade

I. Introduction.

In the proposed 400 MeV Linac Upgrade, the last four Alvarez structure tanks are to be replaced by an eight tank structure of significantly higher gradient. Since five of the tube-based RF systems (for tanks 6 through 9 and the debuncher) are to be replaced by nine Klystron-based RF systems (seven accelerating tanks, a rotation section and a debuncher), it is not possible to simply patch the new RF system into the old control system. The extent to which the control system should be modified is analyzed here.

II. Fundamental Questions.

Presented here are questions which define the scope of the new control system for the Upgrade.

Q 1. How much data will the new Klystron-based RF systems generate (number of A/D and D/A channels) and how does this compare to the existing systems?

A 1. The data required for the existing system is readily available, see Table 1. There is an average of 93 A/D channels for each of the nine RF stations; 81 A/D channels averaged over the 16 stations excluding A and V. There is a total of 1300 A/D channels in the entire Linac, again excluding Stations A and V.

The number of D/A channels is strongly dependant on the number of quadrupole magnets per station. Exclusive of the quads, there is an average of 7 ($\pm$7) D/A channels per station.

The amount of binary information in an average station is 100 bits.

Table 1

A/D Channels in Existing Linac Control System

Station	A/D Channels	D/A Chans	Binary Info	Comments
1	96	35	100 bits	No BPMs yet
2	97	35	100	No BPMs yet
3	95	22	100	No BPMs yet
4	81	19	101	No BPMs yet
5	87	17	110	
6	97	17	102	
7	107	27	100	Trim magnets here
8	86	15	100	
9	88	15	100	
B	62	10	69	Emittance measuring hardware here
C	103		77	
D	35	2	59	
E	89	17	53	Need more room for future BPMs
G	84	25	81	
H	41	9	2	
I	42	9	2	
V	20	0	91	

Determining the number of channels in a Klystron RF system is more difficult, at this time. A channel comparison between a typical existing system and an expected Klystron system is presented in Table 2 (ref. Al Moretti). By this cursory estimate, a Klystron system will have about 50% more channels than an existing system. It is likely that the number of channels in the final systems will be even greater. I will put an upper limit on the first-order guess for the number of channels per Klystron station at 170 (33% more than 129). The total number of channels in the new system is calculated as follows:

$$\begin{aligned}\text{Total Channels} &= (\text{Remaining Channels}) + 7^*(\text{Klystron Station}) + \\ &\quad (\text{Rotation Sta.}) + (\text{Debuncher Sta.}) \\ &= 774 + 1190 + 160 + 80 \\ &= 2204 \text{ Channels}\end{aligned}$$

This is a 70% increase in the number of A/D channels in the entire system.

Table 2

Comparison of A/D Channel Usage for Present and Future Linac Systems

Item	Old System	New System	Comments
RF Gradient Measurement	3	12	3 per module
PA Forward/Reverse Power	2	4	
Driver Fwd/Rev Power	2	2	
A/D Zero Check	2	2	
Low Lev. RF Fwd/Rev Power	2	2	
Other Stages Fwd/Rev Power	4	0	
Feedback system	0	4	
Phase Information	2	4	
Bulk Tuner Position	1	8	2 Tuners per module
Loss Monitors	2	2	
Toroids	2	2	
Beam Position Monitors	8	20	At each module end
Tank Pressure	2	2	
Waveguide Pressure	0	2	
Modulator/Switch Tubes/HV	21	21 ?	Same as now?
Bias Supply Voltage and AC On	0	6	
Filaments	2	2	
Line Voltage	1	1	
Temperature, Humidity	2	2	
Quadrupoles	13, 14	4	
Trim Magnets	0	4	
Ion pump power	1	1	
Calculated Quantities	5	5 ?	More?
Timers	9	9	
Solenoid Currents	0	5	
Water Flow	0	2	
Oil Level	0	1	
Arc Detector	0	1	
Totals	**86**	**129**	
Range of values	35-107	up to 172	

It is reasonable to assume that there will be more devices under computer control in a new system. (Many devices in the current system are not now under computer control, but probably would be in a new system, for example, positioning of bulk tuners, modulator high voltage on/off and certain type of station resets.) The number of D/A channels, including 4 quads and 4 trim magnets, would probably be between 14 and 25. Hence, the total number of D/A channels would be, by the same equation with 20 D/A per Klystron station, approximately 320 channels--a 50% increase over the old system.

Q 2. How quickly will the local control system need to act (CPU speed and I/O speed)?

A 2. The answer to the speed question is the same as it was eight years ago when the current Linac Control System was built, (although now this should be considered only a bare minimum!): Each system needs to be fast enough to read all of its channels, respond to all requests on the network, service local programs and report alarms within one 15 Hz clock tick, 66.6 ms. The current system fulfills this criterion except when a lot stations are requesting some information from a lot of the other stations.[1]

Any modern system should be able to satisfy this "wimpy" criterion quite easily. (The answer to *Q 6* delineates this criterion further.)

Q 3. Why not just replicate the existing control system?

A 3. This is not a reasonable solution for several strong reasons.

First, the hardware for the existing 68000/Multibus system would be very expensive to replicate, if it can be replicated at all. The system was designed just as the 68000 chip was coming on the market and there were no commercially available CPU boards available. The Controls Group built a board of their own design.

Second, new CPU chip and networking technology have improved significantly over the years. Moreover, the industry (i.e., *real* industry, like factories, and research organizations, like FNAL and CERN) is settling on a standard for this type of application which uses the best technology available and is expandable as new technology becomes available.

Third, the large increase in the amount of data in the system (see *A 1*) and the higher expectations we have of a computer control system today (see *A 6*, below) make the old system inadequate.

Fourth, we do not have to give up the good features of the old system, e.g., local control of stations, local access to the system and interchangeability of the system components.

Fifth, it is difficult to justify using valuable laboratory man-power to re-invent the old system. However, using laboratory man-power to develop a new system which more people will understand is worthwhile.

Q 4. What software will need to be written or rewritten to drive the system?

A 4. Some of the existing software will inevitably need to be rewritten. Minor modifications would need to be made in many of the existing Linac application programs. New software to drive the Klystrons will have to be

1The Primary/Secondary relationship of the network is at fault: Each Secondary must ask the Primary to ask the other Secondaries for the information. Since the Primary does not consolidate these requests, the network becomes saturated.

written. It is hoped that the new system will be easily programmed so that people will be eager to write *new* local application programs for the system. It is likely that some linac Front End software will need to be rewritten (more on this later).

Q 5. How will the new control system for the Upgrade impact upon the unaffected linac systems?

A 5. Depending on the form of the new system, there are three ways the existing system is impacted by the new system:

1. Implement the new system in such a way that the old system is entirely unaffected. This would probably require that the present SDLC network be retained and that the new systems be attached to SDLC. It may be difficult to construct new systems which connect to SDLC as this is now an obsolete network. This limits of this network have been observed.

2. Change only the network connection in the old systems. This would probably require that a new Multibus-to-"New Network" card be built.

3. Replace the old system entirely with the new system.

Options 2 and 3 are practical, 1 is not.

Q 6. What new capabilities should be considered for the new control system?

A 6. With a powerful new control system, several interesting local application programs become possible. Here are some I have heard.

With a full complement of beam position monitors and dipole trim magnet pairs, an active beam steering algorithm could be developed; it is not too hard to imagine that this steering could be corrected from pulse to pulse, possibly even *during* the pulse.

Other pulse to pulse adjustments could be made by the control system. For example, pulse to pulse phase and amplitude corrections in the RF, or, with the installation of SWICs, an on-line, pulse to pulse emittance could be implemented. Certainly, the software for scanning a single wire and for directing full-blown emittance calculations could and should be performed locally.

Improved alarm reporting can be accomplished. It is not too hard to imagine a prioritization scheme for a station's alarm reporting. Then, some sort of smart alarms filter could be implemented on the local linac network.

On-line simulations of the linac using a program like *Parmila* would be possible in a local station. One could program each station to predict the beam properties through that section of the linac using the actual A/D values of the pertinent devices and the simulation code. A physicist, or an expert system resident on the network, could analyze the discrepancies between the simulation and the observations and make judgements and recommendations on improvements.

The primary emphasis here is that if the new control system is powerful enough and easy enough to use and if it is understood by many different people, then physicists/engineers/programmers will be motivated to think of new application programs for the system involving new or existing diagnostics tools or using new computational techniques.

III. Possible Hardware Configurations.

Given the basic criteria outlined above, the forms which the hardware could take can now be outlined. Choices must be made on the following: The CPU; the bus and crate configuration; the interface to the existing equipment to be controlled; the interconnections and network among the systems.

The CPU.

The choice of CPUs is restricted to those which are vaguely compatible with existing Accelerator Division systems and which have potential for future enhancement. This rules out, for example, National Semiconductor chips and 8-bit chips like the Z-80. Here are the possible choices with a brief statement on the advantages and disadvantages of each.

1. MC68000. Since replication of the existing control system is not appropriate and since more powerful chips exist for about the same price, this chip should not be seriously considered.
2. MC68020. This is the chip currently being used in the DZero control system being built by Mike Shea, *et al.* It is a very fast and modern CPU chip set. This is the most popular offering from Motorola Corp. today.
3. MC68030. This is possibly the ultimate enhancement of the 68000 line of CPU chip sets (68040 in line?). The chip is not in full production yet, but Motorola says it will be soon. It is a good bit faster than a 68020 at the same clock speed.
4. MC88000. This is Motorola's next generation of RISC-architecture chips. They say that it will be a lot faster than the 68020, I've seen promos for 40 MIPS.
5. Intel 386. This is the processor proposed for the ACNET PDP11 front-end replacements. That system will be developed to speak ACNET and to interface exactly with all the existing Accelerator Division equipment. The primary reason they will use this chip is to avoid developing a general solution to the infamous byte-ordering problem--Intel products have the same byte ordering as DEC products, but the opposite byte ordering from Motorola chips. The 386 chip does not have an on-chip cache memory, as does the 68020. Thus, the expandability of a system based on this chip is questionable.

The Bus and the Crate Configuration.

With the appropriate choice here, the CPU choice becomes less important because well designed CPU boards should be interchangable. The viable alternatives are:

1. VME. Ideally suited for Motorola products (since they invented it). This bus enjoys wide usage by American and European industry and so there are a large number of commercially available products. This is currently the default choice for applications in the Accelerator Division.

2. Multibus II. Well suited for Intel products. Few commercial products are currently available.

3. Multibus I. The bus used in the current system. Obsolete.

Connection to Existing Hardware.

I have only heard one suggestion: MIL-1553. However, new hardware may be connected directly to the bus, *e.g.*, for fast time plots.

Interconnections and Network Among Systems

There are three potential networks available. In each of the choices, the network communications should probably be via light-link to eliminate the possibility of ground loops between stations, in particular, when connecting to the 750 keV domes, although other schemes may be possible.

1. SDLC. Obsolete, see above.

2. Ethernet. This network is not a viable choice for a synchronous system like the Linac. It works best when the distribution of data in time is random and worst when the data happen at periodic intervals. The network can be made to work for a pulsed system like the linac, but only for lots of money.

3. Token Ring, 802.5. Every new system under development in the Accelerator Division is moving towards Token Ring: DZero and ACNET in particular. This is the default choice.

IV. Specific Proposal

Since the expansion of the current control system is not a viable alternative, other proposals need to be developed. One such proposal has been made by Shea. It is an adaptation of the DZero control system, currently under development. (It is noteworthy that the DZero system was, initially, an adaptation of the Linac control system using more versatile and modern technology.) Figure 1 shows the major aspects of this proposal. It would use a MC68020-based CPU board in a VME bus on the Token Ring network.

There are two options on the number of controls stations to build: (a) group the existing RF stations and the Klystron RF stations in pairs or threes, (b) build a complete computer system for each RF system. The criteria for deciding between these two options are overall cost of the system versus the simplicity and power of a one-on-one system.

The advantages of this system are:

1. Very little development work necessary as DZero has already done it
2. Straight-forward to install--should hook right in to existing hardware
3. MC68020/VME/Token Ring is the standard choice in the Accelerator Division for this type of application
4. Compatible with the many present and future secondary control systems in the lab (e.g., DZero, QPM's)
5. Would be compatible, or could be made compatible, with the proposed, new Token Ring ACNET system
6. VME components are available commercially
7. Easy implementation of "wish list" items
8. Plenty of CPU power available for future needs
9. Reasonable Cost/CPU Power ratio
10. Eliminates the Primary
11. Can connect a diagnostic computer/workstation easily, increasing the potential for more efficient trouble shooting and machine physics studies.
12. Conforms to emerging industry standards
13. Can add parallel processors for specific tasks
14. Can have VME-based fast digitizers (100MHz available now) for Linac Fast Time Plots
15. Easy to swap to a more modern CPU (e.g., 68030, 88000)
16. We will have a system which is comprehensible by many people.

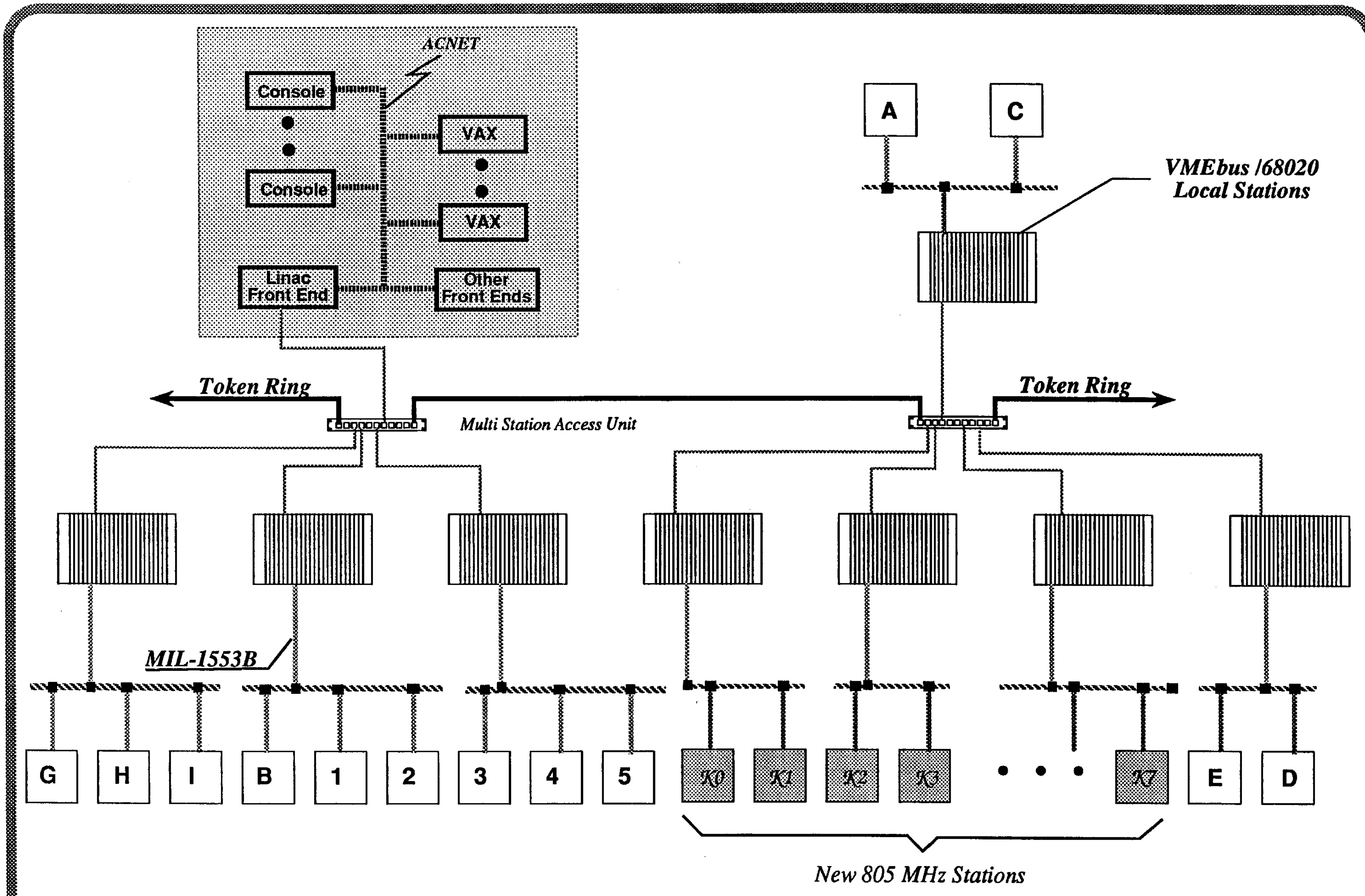
The disadvantages are:

1. Will have to change some application program software
2. Would have to reprogram the Linac Front End, but a general Front End/Token Ring driver is under development now
3. We will either have a lot of extra computing power at each station or the complication of combining stations
4. Retrain Operations and Linac personnel, although nobody really understands the present system

V. Conclusions

The 400 MeV Upgrade for the FNAL Linac will require a computer-based control system for data presentation and analysis and for connection to ACNET. The most fundamental criteria have been discussed and a specific option has been described. A simple expansion of the existing control system will not be adequate to support the new Klystron RF stations. A MC68020/VME/Token Ring system is the default, and a good, choice to replace it. I encourage the reader to suggest further criteria, to critique the proposal or to make some other concrete proposals.

I propose that the 1 MW Klystron test stand, currently under construction, be equipped with one of the proposed DZero-type control systems and connected to the existing lab-wide Token Ring network. Many useful application programs, being developed for the Loma Linda project, can be used immediately on the new system. When the general Token Ring-to-ACNET connection is made (I am told this will happen soon), application programs in the control room can be developed.



Linac Control System using Token Ring/MIL-1553